Pre and Post Earthquake Land Use and Land Cover Identification in Concepción

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Abstract This paper presents the pre and post earthquake identification of representative land cover and land use scenarios in the metropolitan area of Concepción in Chile. Significant land use and land cover changes will be exposed and evaluated conducting a temporal analysis of satellite image classifications.

Keywords Land use · Land cover · Satellite images · Earthquake · Concepción

1 Introduction

As part of the Chilean FONDECYT research project "Evaluation of the Metropolitan Territory using sustainable approaches and strategic environmental assessment", this work presents the identification and evaluation of representative scenarios for land covers and land uses in the metropolitan area of Concepción.

Considering the catastrophic earthquake that affected the study area in February 2010, the land use maps for the years 2009 and 2010, corresponding to pre and post earthquake scenarios (S1 and S2) were updated to visualize the future effects

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on the development processes of the metropolitan area. The need to create these maps, also due to the lack of knowledge on land cover, is of essential importance for describing the spatial process and spatial pattern in a very dynamic metropolitan territory with accelerated urban growth.

The land covers were generated using methods for digital classification of satellite images obtained from Landsat TM (30 m). After the digital processing, the land use data were intensively analyzed and corrected. The cartographic products processed in geographic information systems are highly useful for identifying the changes in land use over the time. In our work we also analyzed the land use changes before and after the earthquake. Thereby comprehensive geospatial analysis of annual changes of land use. Subsequently, the future scenarios for urban growth were generated for the Urban and Territorial Planning of the Metropolitan Area of Concepción (MAC).

2 Study Area

The MAC is located in the southern central zone of Chile between 36°35′ and 37°00′ south latitude and 72°45′ and 73 ° 15′ west longitude. The MAC occupies a coastal territory in the Region of the Biobío. Its limits are established in the Metropolitan Urban Planning of Concepción and consist of 11 interrelated counties that concentrate a population of more than 9,00,000 inhabitants in a surface area of 2,830 Km^2.

The boundaries of MAC include 60 km of coastline, which stretch from north to south, from the county of Tomé to the county of Lota, and in between lay the counties of Concepción, Coronel, Chiguayante, Hualqui, Hualpén, Penco, San Pedro de la Paz, Santa Juana and Talcahuano. MAC settlements have developed primarily in the coastal area, where lower "Bío-Bío River" emerges as its central core. Urbanization and growth in the area follow the grid model (Espinoza and Pérez 2008), i.e., a compact expansion around the central blocks is found, but also an oil stain is spread. The urban structure of settlement is organized in a functionally bi-centric structure that is spatially polycentric; it is restricted due to the limited influence of sub-centers or less important cities in comparison with the principal city centers of Concepción and Talcahuano (Rojas et al. 2009).

3 Methods

3.1 Data Processing

The detection of the land uses was obtained by the processing of two ortho-rectificated Landsat TM 2009 images (path 001/row 085—January 18th of 2009; path 001/row 086—January 18th of 2009) and two ortho-rectificated TM Landsat

Table 1 Themes classes of land uses

Class	Description
1. Built-up areas	Built areas occupied by cities or industrial installations
2. Native forest	Ecosystem which its arboreal stratum is established by natural species; mainly different kind of forests such as: Coihue, Olivillo, Patagua, Boldo.
3. Bush	Areas where the presence of trees is less than 25 %, bushes between 10 and 100 %, and herbaceous between 0 and 100 %
4. Water spaces	Rivers, lakes and lagoons
5. Open land	Non cultivated areas without buildings: cut zones, burned areas, eroded areas and areas with almost no vegetation
6. Plantation	Forest which arboreal stratum is mainly formed by exotic species
7. Beaches, dunes and grounds	Beaches, dunes and grounds
8. Grassland	Vegetal formations where the herbaceous cover is above 25 % and the kind of trees and bushes have a spread area of <25 %; it includes the territories with rotative cultivation and hardback
9. Agricultural lands	Utilized agricultural area including cereals, horticulture and fruit cultives
10. Wetlands	Surfaces covered by pure or artificial waters, temporary or permanent waters, stable or running waters, sweet or salty waters; it includes permanent herbaceous vegetation flooded in the riversides, herbaceous wetlands and bushes, peatlands, among others moist or wetlands
11. No data	Misclassified areas without image coverage, active fires (smoke feathers) or areas fully covered by clouds

2010 images (path 001/row 085—March 26th of 2010; path 001/row 086—March 26th of 2009 post-earthquake). Both of the images were taken with a resolution of 30 m. The scenes were processed and the radiometric and the geometrics corrections were made. The georeferencing (Polynomial, Orden 3) was made according to the vectorial covers and specific control locations taken on the field.

3.2 Legend and Classification

The definition of the different theme classes were established according to the covers proposed in the map of land uses and the forest covers in 1998 by the Conaf et al. (1999). Furthermore different investigations on generalizations are proposed in the study area (Rojas, et al. 2010).

The most important aspect was the precise knowledge in the area of the “Bío-Bío” region. Furthermore some classifications methods were applied highlighted in the study of Aguayo (Aguayo et al. 2009). According to the information presented the following themes were chosen to work with (Table 1).

According to the revised bibliography and in agreement with the used images, the unsupervised classification is dismissed. Thus it is decided to follow a supervise classification. Maximum Likelihood (ML) therefore is a suitable method for the objectives in our work, especially when the source of information corresponds to Landsat satellite images (Aguayo et al. 2009; Bakr et al. 2010; Shalaby and Tateishi 2007; Wentz et al. 2006; Yuan et al. 2005). The ML classifier is a widely accepted classification method because of its robustness and simplicity. The classifier determines the probability that a pixel belongs to each class and then assigns the pixel to the class with the highest probability (Richards 1999). It assumes that the spectrum of each class is normally distributed and requires that the class be defined by a minimum n + 1 training pixels for n spectral bands (Platt and Goetz 2004). In 2009 Al-Ahmadi and Hames evaluated four classification methods to extract land use and land cover, they found that the maximum likelihood method gave the best results.supervised classification algorithms need a prior knowledge of the study area, in this sense visual recognitions were made (interpretations, aerial photography and land maps (Al-Ahmadi and Hames 2009; Conaf et al. 1999)). These recognitions allow obtaining training places (polygons) for each of the theme classes in every year of study. Later, the training areas were submitted to a statistical analysis of separability that allowed distinguishing the distance between classes and the feasibility of its discrimination.

3.3 Validation

The validation of the exact classifications was made through the confirmation of specific land spots, locations that were important to verify. First 100 of random places were generated within an area logistically accessible. Because of that a buffer with a distance less than 100 meters off the highways, roads and rural paths was considered. These spots are generally located in the waterfront, an area especially affected by the earthquake and tsunami that occurred in February 27th 2010.

Later, 250 random places were checked every year, specifically 25 spots in each of the 10 covers (excluding the "non data class"). With the processed information it was possible to obtain the level of error of the classifications per year. With the purpose to obtain the previous information the statistical accuracy Kappa was used.

4 Results

4.1 Analysis of the Separability

Considering separability values over 1.5 as an optimal distance of separability, the results of the analysis possibly showed more confusion (values < 1.5) between grassland covers (8) and the agricultural lands (9), being put together in the same class according to its spectral characteristics. If a precise separation between classes is required, especially for later ecological focused studies, it is necessary to make use of images during different seasons, so that the comparison of the phenological differences can be made.

At the same time the boundaries between beach zones (7), sediments with open lands (5) and urbanized areas are highly dependent on the interpretation because of its low spectral separability. In these areas the earthquake and the tsunami of February 27th 2010 had a major influence, because they caused confusing zones wherein tree covers were mixed. In this case the accurate knowledge of the area is extremely useful to establish context criteria that contribute to the improvement of the classification and its results.

The covers of the native forest (2) and forest plantations (6) also generated confusion (values less than 1.4) especially in places where the native forests are fragmented and organized in patches completely surrounded of the exotic plantations of pine tree or eucalyptus.

Important part of the covers showed appropriate values of separability, above 1.0 value.

4.2 Maps Land Use and Land Cover

In Fig. 1. Two maps of the scale 1:50,000 are shown. These maps were obtained by the classification using MAC before and after the earthquake and tsunami, which occurred on February 27th of 2010.

Comparing the land cover of both years (before and after the earthquakes) it was detected that the major coverage was the forest plantation (>95,000 ha; >30 %). These forest plantations are mainly distributed in slopes of mountains of the coastal range. There the predominant species are pine tree and eucalyptus trees, with a very high density in the south of the "Bío-Bío River".

The brushwood characterized by shrubs increased its amount (>58,000 ha) from a 20 % (2009) to 22 % (2010). They are located in places with high slopes.

Within the areas of open lands (>16 %) only a slight reduction was determined. These places are characterized by small spaces next to the urbanized areas and agricultural land, also by extensive grounds in the north area, known as the dry coastal zone.

The agricultural land (>19,000 ha) has decreased from 27,000 to 19,000 ha, reducing its presence to 7 %.

The grassland highly associated to the uses mentioned before, mainly because of the rotations in the cultivation of the grassland. Grassland areas (8,000 ha) increased up to 3 %. Therefore a main characteric is the neutrality and the presence of the exotic herbaceous species.

The native forests represented a bit more than 5 % with more than 14,000 ha in 2009. In 2010 almost 18,000 ha were detected. These forests are located in humid areas with natural streams. The forests are surrounded by forest plantations;

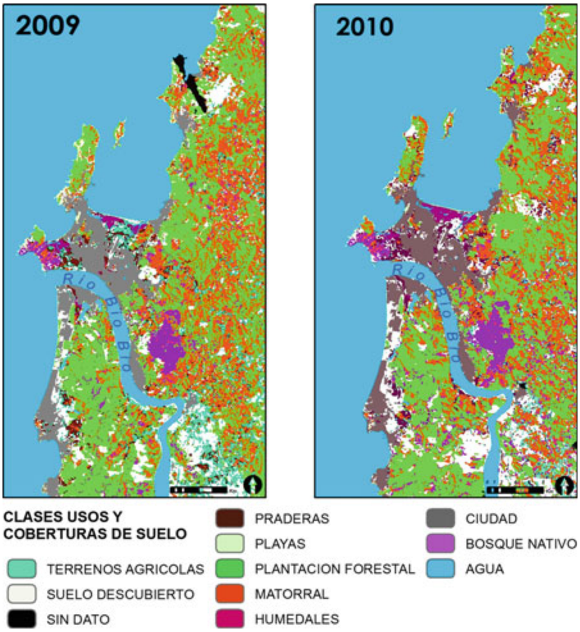


Fig. 1 Scenarios of land use cover, S1 before (*left*) and S2 after (*right*) the earthquake (Terrenos Agrícolas = Agricultural land; Suelo Descubierto = Uncovered land; Sin dato = No data; Praderas = Grassland; Playas = Beaches and dunes; Plantation Forestal = Planted forest; Matorral = Brushwood areas; Humedal = Wetland; Ciudad = built-up area; Bosque Nativo = Native Forest; Agua = Water)

probably this reason can be explain the increments of native forests, mainly for the confussion between both categories.

The coastal beaches (0.5 %) have being reduced in the surface from 2,900 to 1,600 ha (reduction of 55 %).

The wetland areas contain more than 1,000 ha, and nowadays represent the 0.45 % of MAC area. Wetlands are located in places associated to the presence of water (estuaries, lagoons, rivers).

The built-up areas have been reduced to 290 ha, but they keep their representativeness of 6 % with more than 17,000 urbanized hectares. They are located mainly in marine terraces. Finally, the water coverage represents 4 % of the total surface with more than 11,000 ha, being the most important source of the "Bío-Bío river" (Table 2).

4.3 Validation: True Land Versus Classifications

The validation of the verification spots showed a coefficient (Kappa) for the year 2009 of 0.78 and for the year 2010 of 0.77. That is to say that 78–77 % of the pixels of the land covers are properly classified.

The territories where the classes or covers represented major identification problems were the transitions between beaches, open lands and urban places in the coastal zones. Thereby wetlands and grasslands in areas of humid grounds had

Table 2 Surfaces changes of land use and land cover

Land use/ cover	Area 2009 (ha)	Percentage of area 2009	Area 2010 (ha)	Percentage of area 2010	Change (ha)	Change (%)
Built-up areas	17,381	6.07	17,087	5.97	−294	−1.69
Native Forest	14,557	5.09	17,917	6.26	3,360	23.08
Brushwood areas	58,884	20.57	63,547	22.20	4,663	7.92
Water	11,956	4.18	11,622	4.06	−334	−2.79
Uncovered land	50,063	17.49	46,282	16.17	−3,781	−7.55
Planted Forest	95,258	33.28	98,327	34.35	3,069	3.22
Beaches and dunes	2,957	1.03	1,679	0.59	−1,278	−43.22
Grassland	6,497	2.27	8,929	3.12	2,432	37.43
Agricultural Land	27,634	9.65	19,504	6.81	−8,130	−29.42
Wetlands areas	1,040	0.36	1,331	0.47	291	27.98

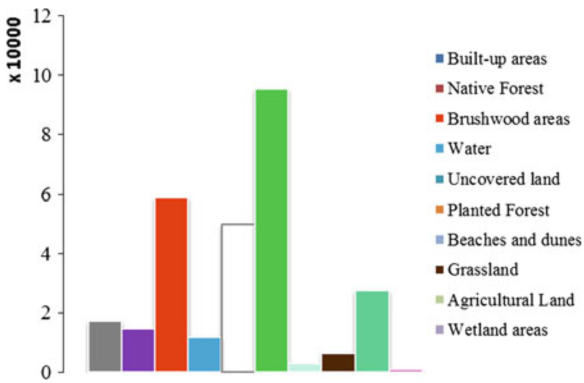


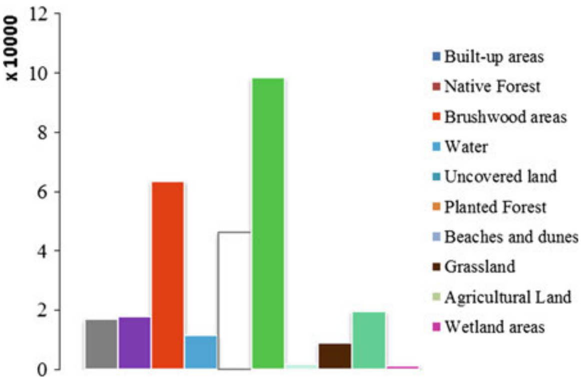
Fig. 2 Graphics surfaces of land use and land cover

important influence. In the inland there is a mixture between forest plantations, native sclerophyll forests and bushes (Figs. 2 and 3).

5 Discussion and Conclusion

In the land uses and land covers presented in this paper, the most difficult cover to identify was the beach class. This was characterized by presenting low spectral separability. It was mixed with the open lands in the coast of Tomé and Penco and with the cliff located in Talcahuano.

Fig. 3 Graphics surfaces of land use and land cover



Also the investigation on the mixture between urban zones, debris (because of the catastrophe) and open lands showed an identification of extensively mixed zones, decreasing the occupied surface for the beaches. The coastal zone (Talcahuano, Penco and Tomé) especially the bays oriented to the north were devastated by the earthquake and by the tsunami. These places were crushed by waves of >3 m in Talcahuano (European Commission 2010). Some authors have documented wave lifts of 0.5 ± 0.1 m in Talcahuano creeks (Quezada et al. 2010). Certainly, the natural landscape has shown up important variations. The built-up area has been reduced by the material lost and the housing damages located in the coast.

The covers that presented some complexity in its identification are wetlands and native forests areas. In this classification, the wetlands correspond to a humid land belted by water. Vegetation is also a part of the wetland ecosystem which was recognized in these maps as grasslands.

The native forests or non-forests are made of sclerophyllous species such as Olivillo, Peumo, Boldo, Hualle (tree species). The detection is accurate when the presence of these trees is important. However, in the remaining spaces which are surrounded by forest plantation, the detection of certain tree species can not be done clearly.

The interrelationships between forest plantations and bushes also present some inaccuracies, especially when the forest plantations are in the growing phase. In many cases these spaces were classified as bushes, justifying its increment.

The valid classifications are the ones that are in an exact level with accuracy above 70 %. The content of these maps are equal to the regional studies, using an inferior scale of 1:50,000. The maps constitute a considerable contribution to the development of study areas, especially in ecology and territorial planning. For example it would be efficient and important to evaluate the natural ecosystem conditions and the natural risks threat.

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